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## Smoking behaviours and indoor air quality: a comparative analysis of smoking-permitted vs. smoke-free homes in Dhaka, Bangladesh

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### ABSTRACT

**Introduction** Exposure to second-hand smoke (SHS) is a health risk to non-smokers. Indoor particulate matter (PM<sub>2.5</sub>) is associated with SHS exposure and is used as a proxy measure. However, PM<sub>2.5</sub> is non-specific and influenced by a number of environmental factors, which

are subject to geographical variation. The nature of association between SHS exposure and indoor PM<sub>2.5</sub> -studied primarily in high-income countries (HICs) context- may not be globally applicable. We set out to explore this association in a low/middle-income country setting, Dhaka, Bangladesh.

**Methods** A cross-sectional study was conducted among households with at least one resident smoker. We inquired whether smoking was permitted inside the home (smoking-permitted homes, SPH) or not (smoke-free homes, SFH), and measured indoor PM<sub>2.5</sub> concentrations using a low-cost instrument (Dylos DC1700) for at least 22-hours. We describe and compare SPH and SFH and use multiple linear regression to evaluate which variables are associated with PM<sub>2.5</sub> level among all households.

**Results** We surveyed 1,746 households between April and August 2018; 967 (55%) were SPH and 779 (45%) were SFH. The difference between PM<sub>2.5</sub> values for SFH (median 27 µg/m<sup>3</sup>, IQR 25) and SPH (median 32 µg/m<sup>3</sup>, IQR 31) was 5 µg/m<sup>3</sup> (p<0.001). Lead participant's education level, being a non-smoker, having outdoor space and smoke-free rule at home, and not using kerosene oil for cooking were significantly associated with lower PM<sub>2.5</sub>.

**Conclusions** We found a small but significant difference between PM<sub>2.5</sub> concentrations in SPH compared to SFH in Dhaka, Bangladesh – a value much lower than observed in HICs.

## INTRODUCTION

Exposure to second-hand smoke (SHS) is a serious health hazard among non-smoking adults and children.[1] The harmful consequences of SHS mostly affect women and children by causing lower respiratory infections,[2] middle ear disease,[3] tuberculosis,[4] chronic obstructive pulmonary disease (COPD) and exacerbation of asthma.[2] Globally, every year,

around 890,000 lives and 10.9 million disability-adjusted life years (DALYs) are lost because of SHS exposure.[5]

There are several well-accepted objective methods to assess SHS exposure such as measurement of nicotine or particulate matter (PM<sub>2.5</sub>) in the air or cotinine in body fluids as a biomarker of inhaled nicotine.[6] While nicotine and cotinine are tobacco-specific, airborne PM<sub>2.5</sub> is not. Despite this, indoor PM<sub>2.5</sub> concentration has been widely used as a marker of SHS and is a useful indicator for evaluating indoor smoke-free policies.[7-9] PM<sub>2.5</sub> concentrations have also been shown to be several times higher in smoking-permitted homes (SPH) compared to smoke-free homes (SFH).[10-13] Moreover, factors such as the presence and number of smokers living in the home, the number of smokers who smoke on a daily basis, number of cigarettes smoked, location of smoking inside the home (bedrooms, kitchen), types of tobacco products used, and household ventilation influence the concentration of indoor PM<sub>2.5</sub>. [13, 14] However, the nature of association between PM<sub>2.5</sub> and SHS is based on data collected from high-income countries (HICs) and little is known about the presence and magnitude of these associations in the rest of the world. We aimed to study the association between indoor PM<sub>2.5</sub> levels and SHS in a lower/middle-income country (LMIC) setting, where most of the previous studies have looked at PM<sub>2.5</sub> in relation to stoves or cooking fuels. This is important for two reasons. Firstly, the number of smokers is rising in LMICs[15] with an accompanying increase in SHS exposure.[16] Secondly, PM<sub>2.5</sub> is influenced by a wide range of outdoor (e.g. motor vehicles, construction, industrial processes, desert dust) and indoor (e.g. cooking and biomass fuel combustion) sources,[17, 18] which are likely to differ between HIC and LMIC contexts. For example, there is higher ambient air pollution, use of a range of domestic fuels, and greater

air exchange rates through ventilation in many LMIC settings compared to HICs. As low-cost PM<sub>2.5</sub> counting instruments such as the Dylos DC1700 are becoming increasingly accessible in LMIC,[19] it is timely to assess if PM<sub>2.5</sub> can be used as a marker of SHS[6] in such settings.

In this paper, we compare indoor PM<sub>2.5</sub> concentrations between SFH and SPH, and identify other factors that may be associated with differences in concentrations.

## **METHODOLOGY**

### **Study design and settings**

This cross-sectional design used baseline data collected as part of a cluster randomised controlled trial (cRCT) called Muslim Communities Learning About Second-hand Smoke in Bangladesh (MCLASS II).[20] This cRCT aimed to evaluate the effectiveness and cost-effectiveness of a community-based intervention to improve domestic indoor air quality in Dhaka, Bangladesh. We included 1746 recruited households. Ethics approval was received from the Health Sciences Research Governance Committee at University of York (Approval date 8 August 2017) and Bangladesh Medical Research Council (BMRC) (Reference: BMRC/NREC/2016–2019/358) prior to the study.

### **Study participants**

We recruited households with at least one adult resident who smoked cigarettes or other form of tobacco (e.g. bidi, shisha) regularly (at least 25 out of 30 days/month) and at least one other non-smoking resident. We excluded households that used coal or biomass fuel for cooking or other domestic purposes since we expected that such combustion sources would mask the effect

of smoking on indoor PM<sub>2.5</sub> concentrations. Each household nominated a ‘lead participant’ who consented and completed the household questionnaire. There were no restrictions on which member of the household the lead participant could be, provided they were an adult resident; they could be either a smoker or a non-smoker.

## Data

Data were collected by trained field investigators (FIs). A structured questionnaire was used to collect household-level data including: number of adults, children, smokers and bedrooms; presence of adjacent outdoor spaces (such as garden, yard, balcony, or veranda); type of fuel used for cooking (electric/LPG/natural gas/biogas, kerosene); indoor smoking rules for residents and visitors; and asset index value. Since household income is a fluctuating variable and often subject to measurement bias, asset index was used as a proxy measure for household wealth and hence their long-run economic status.[21] Questions on access to electricity, flush toilet, fixed telephone, cell phone, television, radio, refrigerator, car, motorcycle, and cattle were asked. First, asset weight for each of the households was calculated following a standard Principal Component Analysis (PCA).[21, 22] Then, by using this specific weight for a household and its holding status of the aforementioned asset, asset index for each household was calculated.

The following individual-level data for the lead participant were collected: age, sex (male, female), highest education years (completed years of education), and current smoking status (smoker, non-smoker). Where the lead participant was a smoker, the following individual-level data were also collected: use of different tobacco products (e.g. cigarette, Bidi), number of total

tobacco products consumed daily, and number of days of smoking in the last 30 days. However, we were unable to assess the dose-response outcome between tobacco smoked (number of tobacco product consumed inside or outside home) and PM<sub>2.5</sub>, as the goal of this trial was to achieve complete abstinence of indoor smoking.

In addition, we used Dylos DC1700 (Dylos Inc., CA, USA) machines installed in the households to measure and record indoor airborne particulate concentrations (PM<sub>2.5</sub>) every minute. These devices were placed in the main living room of each home as far as possible from the kitchen and windows. They were plugged in and run from mains electricity; a 400 BDT (equivalent to US\$5) incentive was offered to compensate for the increased electricity costs and household members' time spent completing questionnaires. In the case of a power cut, the battery was able to support the device for up to six hours. The devices were installed in homes for at least 24 hours, with the aim to record a full 24 hours' of data, though data were accepted if no less than 22 hours of recordings were available. If less than 22 hours of data were recorded in the first instance (perhaps due to machine failures or the device being mistakenly switched off by a member of the household), two further attempts were made over the next few days in which the devices were reinstalled in the homes and left for a minimum of 24 hours. Fine particle number concentrations were converted to PM<sub>2.5</sub> mass concentrations using an established methodology.[19] Each Dylos DC1700 device was calibrated against a factory-calibrated TSI Sidepak AM510 Personal Aerosol Monitor (TSI Inc, MN, USA).

## **Data Analysis**

We stratified the households into two groups - those that permitted smoking indoors (SPH), and those that did not (SFH). SFH status was based on responding ‘only outside’ to two questions: “Are people who live with you allowed to smoke...?” and “Are people who visit your house (including family members), allowed to smoke...?”. Homes were considered as SPH if residents or visitors were allowed to smoke in any part of the inside of the home. Household and the lead participant characteristics are presented and compared across the two groups (SFH and SPH) using a t-test for continuous variables (or the Mann-Whitney U test where data were not normally distributed) and the chi-square test for categorical variables. A small number of households allowed visitors to smoke inside the home but not residents, these were classed as SPH in the main analyses, but exploratory descriptive analyses of PM<sub>2.5</sub> values were conducted with these households reallocated to the SFH group.

Ordinary least squares multiple linear regression was conducted including all households with the outcomes of average and maximum household PM<sub>2.5</sub> (µg/m<sup>3</sup>) values, and household-level and lead participant-level characteristics as independent variables. We specified three different models for each outcome. The first only included lead participant-level independent variables. The second included both lead participant- and household-level independent variables. The third added SFH/SPH status to the model. Goodness of fit in each model was assessed using the adjusted R-squared statistic. Model assumptions were checked using a QQ plot to assess the normality of residuals, and a scatter plot of fitted values versus residuals, and White’s test[23], to assess heteroscedasticity. Residuals from the models using untransformed outcome data were not normally distributed, so PM<sub>2.5</sub> data were log-transformed for the final analysis models, which significantly improved model fit (see supplement material 1).

For each model, we assessed multicollinearity (using the variance inflation factor (VIF), where a VIF greater than 10 may suggest concerning correlation between the explanatory variables.

Statistical significance was assessed using two-sided tests at the 5% level. We used Stata version 15 for all analysis.

## RESULTS

Data were collected between April and August 2018, for 1801 households. Data for 55 households could not be used as at least 22 hours' of PM<sub>2.5</sub> measurements were not achieved. We therefore analysed data from 1746 households; 967 (55%) were SPH and 779 (45%) were SFH (Table 1).

Table 1. Characteristics of household and ambient air (PM <sub>2.5</sub> ) stratified by whether the home is defined as being 'smoke free' or not				
Household Characteristics	Smoke free homes (SFH)  (n=779)	Smoke-permitted homes (SPH)  (n=967)	Total  (n=1746)	Associated test p-value <i>t-test</i> <sup>a</sup> <i>chi2 test</i> <sup>b</sup> <i>Mann-Whitney U test</i> <sup>c</sup>
Number of adults in household				
Mean (SD)	2.5 (0.8)	2.3 (0.7)	2.4 (0.8)	<0.001 <sup>c</sup>
Median (min, max)	2 (1, 6)	2 (1, 6)	2 (1, 6)	
Number of children in household				
Mean (SD)	1.4 (1.1)	1.4 (1.1)	1.4 (1.1)	0.39 <sup>c</sup>
Median (min, max)	1 (0, 7)	1 (0, 6)	1 (0, 7)	
Number of smokers				
Mean (SD)	1.1 (0.3)	1.1 (0.3)	1.1 (0.3)	0.05 <sup>c</sup>
Median (min, max)	1 (1, 3)	1 (1, 3)	1 (1, 3)	



Number of bedrooms				
Mean (SD)	1.5 (0.7)	1.3 (0.6)	1.4 (0.7)	<0.001 <sup>c</sup>
Median (min, max)	1 (0, 6)	1 (1, 5)	1 (0, 6)	
Home has outdoor space, n (%)				
Yes	495 (63.5)	450 (46.5)	945 (54.1)	<0.001 <sup>b</sup>
No	284 (36.5)	517 (53.5)	801 (45.9)	
Fuel used for cooking, n (%)				
Electricity	77 (9.9)	70 (7.2)	147 (8.4)	0.05 <sup>b</sup>
LPG/natural gas/biogas	705 (90.5)	902 (93.3)	1607 (92.0)	0.03 <sup>b</sup>
Kerosene	29 (3.7)	33 (3.4)	62 (3.6)	0.73 <sup>b</sup>
Asset Index				
Mean (SD)	0.4 (4.9)	0.3 (4.4)	0.4 (4.7)	<0.001 <sup>c</sup>
Median (min, max)	-0.5 (-0.9, 44)	-0.3 (-0.8, 44)	-0.3 (-0.9, 44)	
*Maximum PM <sub>2.5</sub> value, µg/m <sup>3</sup>				
Mean (SD)	309.3 (285.8)	372.6 (290.4)	344.3 (290.0)	<0.001 <sup>c</sup>
Median (min, max)	208.0 (21.0, 1376.0)	286.0 (20.0, 1304.0)	248.5 (20.0, 1376.0)	
IQR	342	419	377	
*Mean PM <sub>2.5</sub> value, µg/m <sup>3</sup>				
Mean (SD)	38.4 (34.3)	45.2 (40.6)	42.2 (38.0)	<0.001 <sup>c</sup>
Median (min, max)	27.0 (2.0, 290.0)	32.0 (1.0, 422.0)	30.0 (1.0, 422.0)	
IQR	25	31	28	
*Maximum PM <sub>2.5</sub> value: Maximum 1-minute derived value for each household				
*Mean PM <sub>2.5</sub> value: An average of 1440 minutes of data was collected for each household				

SPH tend to have fewer adult residents, fewer bedrooms, not have outdoor space and not use electricity for cooking as compared to SFH. Average household PM<sub>2.5</sub> concentration was significantly higher among SPH than SFH (mean 45.2 [SD 40.6, median 32.0] compared to 38.4 [SD 34.3, median 27.0]; p<0.001). 'One-minute household maximum PM<sub>2.5</sub> concentration' was also significantly higher among SPH than SFH (mean 372.6 [SD 290.4, median 286.0] compared to 309.3 [SD 285.8, median 208.0]; p<0.001).

In additional analyses, in which we reallocated SPH homes where smoking was permitted by visitors only (21 households) to the SFH group, the mean and maximum PM<sub>2.5</sub> values were almost identical to the original categories.

To demonstrate differences in short term concentrations within homes where smoking did and did not take place, the distribution of minute-by-minute PM<sub>2.5</sub> concentrations in SPH and SFH are shown in Figure 1. SPH were significantly right-shifted compared to SFH indicating more individual minutes at higher concentrations (Kolmogorov-Smirnov test  $p < 0.001$ ). Overall, 5.6% of minutes in SPH had concentrations higher than 150.4 µg/m<sup>3</sup> (the US Environmental Protection Agency's threshold for "very unhealthy" concentrations)[24] compared to 4.2% of minutes in SFH.

Lead participants in SPH were more likely to be male, to have completed fewer years' education, and to be a current smoker than in SFH (Table 2). In addition, smoker lead participants in SPH tended to smoke more cigarette and have a higher daily consumption compared to SFH.

**Table 2.** Characteristics of household lead stratified by whether the home is defined as being 'smoke free' or not

Lead participant's Characteristics	Smoke free homes (SFH) (n=779)	Smoke-permitted homes (SPH) (n=967)	Total (n=1746)	Associated test p-value <i>t</i> -test <sup>a</sup> <i>chi</i> <sup>2</sup> test <sup>b</sup> <i>Mann-Whitney U</i> test <sup>c</sup>
<b>Age, years</b>				
Mean (SD)	39.5 (12.5)	40.5 (12.5)	40.1 (12.5)	0.12 <sup>a</sup>

Gender, n (%)				
Male	724 (92.9)	939 (97.1)	1663 (95.2)	<0.001 <sup>b</sup>
Female	55 (7.1)	28 (2.9)	83 (4.8)	
Highest education years, n (%)				
Mean (SD)	6.4 (5.0)	4.1 (4.2)	5.1 (4.7)	<0.001 <sup>a</sup>
Current smoking status, n (%)				
Non-smoker	133 (17.1)	42 (4.3)	175 (10.0)	<0.001 <sup>b</sup>
Smoker	646 (82.9)	925 (95.7)	1571 (90.0)	
Among the smoker lead participants	n (%) = 646 (41.1)	n (%) = 925 (58.9)	n (%) = 1571 (100.0)	
Only cigarette smoker n (%)				
Cigarette	645 (99.8)	895 (96.8)	1540 (98.0)	<0.001 <sup>b</sup>
Other	1 (0.2)	30 (3.2)	31 (1.9)	
Only bidi smoker n (%)				
Bidi	7 (1.1)	70 (7.6)	77 (4.9)	<0.001 <sup>b</sup>
Other	639 (98.9)	855 (92.4)	1494 (95.1)	
Median (min, max)	10 (3, 20)	10 (4, 40)	10 (3, 40)	
Total tobacco product (cig/bidi) consumed/day				
Mean (SD)	10.3 (5.5)	14.4 (7.9)	12.7 (7.3)	<0.001 <sup>a</sup>
Number of days smoked any tobacco product in last 30 days				
Mean (SD)	29.6 (1.3)	29.9 (0.6)	29.8 (0.9)	<0.001 <sup>c</sup>
Median (min, max)	30 (25, 30)	30 (20, 30)	30 (20, 30)	

In the first model for mean PM<sub>2.5</sub>, we observed that years of education (p<0.001) and smoking status (p<0.001) of the lead participant are statistically significantly associated with air quality (Table 3). The effect of education is very small, however; for every additional year of education, the average household PM<sub>2.5</sub> value reduces by a factor of 0.98 (95% CI 0.97 to 0.99). The mean PM<sub>2.5</sub> value of the households for which the lead participant is a smoker is, on average, 1.31 times higher (95% CI 1.14 to 1.51) than households where the lead participant is not a smoker.

**Table 3.** What factors predict average PM value? Three multiple linear regression models with log-transformed mean PM<sub>2.5</sub> value as the outcome.

Variable (reference variable)	Model 1 (Characteristics of lead participant)		Model 2 (Characteristics of lead participant and household)		Model 3 (Characteristics of lead participant and household and their indoor smoking policy at home)	
	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
Age	-0.001 (-0.004, 0.001)	0.32	-0.001 (-0.004, 0.002)	0.43	-0.001 (-0.004, 0.001)	0.30
<b>Gender (male)</b>						
Female	0.12 (-0.06, 0.31)	0.19	0.10 (-0.08, 0.29)	0.28	0.11 (-0.08, 0.29)	0.26
Highest education grade	-0.02 (-0.03, -0.01)	<0.001***	-0.02 (-0.03, -0.01)	<0.001***	-0.02 (-0.03, -0.01)	<0.001***
<b>Lead participant smoking status (non-smoker)</b>						
Smoker	0.27 (0.13, 0.41)	<0.001***	0.22 (0.07, 0.36)	0.003**	0.19 (0.05, 0.34)	0.009**
Asset index	--	--	-0.002 (-0.01, 0.00)	0.51	-0.002 (-0.01, 0.00)	0.47
Number of adults in household	--	--	-0.04 (-0.09, 0.02)	0.17	-0.03 (-0.09, 0.02)	0.24
Number of children in household	--	--	0.02 (-0.01, 0.05)	0.17	0.02 (-0.01, 0.05)	0.12
Number of smokers	--	--	0.01 (-0.11, 0.13)	0.90	-0.003 (-0.13, 0.12)	0.97
Number of bedrooms	--	--	0.05 (-0.00, 0.11)	0.06	0.05 (-0.00, 0.11)	0.06
<b>Home has outdoor space (No)</b>						
Yes	--	--	-0.15 (-0.21, -0.08)	<0.001***	-0.14 (-0.20, -0.07)	<0.001***
<b>Fuel used for cooking (Electricity/ LPG/natural gas/biogas)</b>						
Kerosene	--	--	0.67 (0.50, 0.84)	<0.001***	0.67 (0.51, 0.84)	<0.001***
<b>Indoor smoking policy of home (Smoke-free home)</b>						
Smoke-permitted home	--	--	--	--	0.08 (0.01, 0.14)	0.02**
Total observations	1,746		1,746		1,746	
F (Probability)	18.8 (<0.001***)		14.6 (<0.001***)		13.9 (<0.001***)	

<b>Adjusted R-square</b>	0.039	0.079	0.081
P-value significance level: 10% (*), 5% (**), 1% (***)			

In the second model for mean PM<sub>2.5</sub>, education level (p<0.001) and smoking status (p=0.003) of lead participant remain statistically significant correlates, with similar magnitudes of effect. In addition, use of kerosene as a cooking fuel was found to almost double the indoor air pollution (multiplies expected value of mean PM<sub>2.5</sub> by 1.95, 95% 1.65 to 2.32, p<0.001) relative to households that do not use kerosene, while having an outdoor space is associated with a significant reduction in average PM<sub>2.5</sub> by a factor of 0.86 (95% CI 0.81 to 0.92, p<0.001).

In the third model, the magnitude and significance of the covariates affecting the air quality were found to be reasonably consistent with the previous model. In addition, there was evidence that SPH status is predictive of PM<sub>2.5</sub> (p=0.02), though the difference is very small; the average estimated PM<sub>2.5</sub> value was 8% higher (95% CI 1% to 15%) in SPH relative to SFH.

The VIF ranged from 1.39 to 1.40 for all three models and no evidence of heteroscedasticity was found in any of the models.

As with average PM<sub>2.5</sub>, education level and smoking status of the lead participant were significantly associated with maximum PM<sub>2.5</sub> in all three models (Table 4). In models 2 and 3, an increase in household asset index was observed to be associated with a very small but statistically significant decrease in maximum PM<sub>2.5</sub>, as were the lead participant not being a smoker, having outdoor space and not using kerosene for cooking, though these effects were

larger. In model 3, age of the lead participant was statistically significant but the magnitude of the effect was negligible. On average, the maximum PM<sub>2.5</sub> was 1.17 times higher than in SFH (95% CI 1.06 to 1.28, p=0.001).

**Table 4.** What factors predict maximum PM value? Three multiple linear regression models with log-transformed maximum PM<sub>2.5</sub> value as the outcome.

Variable (reference variable)	Model 1 (Characteristics of lead participant)		Model 2 (Characteristics of lead participant and household)		Model 3 (Characteristics of lead participant and household and their indoor smoking policy at home)	
	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
<b>Age</b>	-0.003 (-0.01, 0.00)	<b>0.07*</b>	-0.004 (-0.01, 0.00)	<b>0.09*</b>	-0.004 (-0.01, -0.00)	<b>0.04**</b>
<b>Gender (male)</b>						
<i>Female</i>	-0.005 (-0.27, 0.26)	0.97	-0.04 (-0.30, 0.23)	0.79	-0.03 (-0.29, 0.23)	0.83
<b>Highest education grade</b>	-0.04 (-0.05, -0.03)	<b>&lt;0.001***</b>	-0.03 (-0.04, -0.02)	<b>&lt;0.001***</b>	-0.03 (-0.04, -0.02)	<b>&lt;0.001***</b>
<b>Lead participant smoking status (non-smoker)</b>						
<i>Smoker</i>	0.32 (0.12, 0.51)	<b>0.001**</b>	0.25 (0.04, 0.45)	<b>0.02**</b>	0.20 (-0.00, 0.41)	<b>0.05*</b>
<b>Asset index</b>	--	--	-0.01 (-0.02, -0.00)	<b>0.02**</b>	-0.01 (-0.02, -0.00)	<b>0.02**</b>
<b>Number of adults in household</b>	--	--	-0.05 (-0.13, 0.03)	0.19	-0.04 (-0.12, 0.04)	0.30
<b>Number of children in household</b>	--	--	0.02 (-0.02, 0.06)	0.39	0.02 (-0.02, 0.07)	0.27
<b>Number of smokers</b>	--	--	-0.01 (-0.18, 0.17)	0.92	-0.03 (-0.21, 0.14)	0.74
<b>Number of bedrooms</b>	--	--	0.11 (0.03, 0.19)	<b>0.008**</b>	0.11 (0.03, 0.19)	<b>0.007**</b>
<b>Home has outdoor space (No)</b>						
<i>Yes</i>	--	--	-0.22 (-0.31, -0.13)	<b>&lt;0.001***</b>	-0.21 (-0.29, -0.11)	<b>&lt;0.001***</b>

Fuel used for cooking ( <i>Electricity/ LPG/natural gas/biogas</i> )						
<i>Kerosene</i>	--	--	0.83 (0.59, 1.07)	<0.001***	0.84 (0.61, 1.08)	<0.001***
Indoor smoking policy of home ( <i>Smoke-free home</i> )						
<i>Smoke-permitted home</i>	--	--	--	--	0.16 (0.06, 0.25)	0.001**
Total observations	1,746		1,746		1,746	
F (Probability)	22.7 (<0.001***)		15.4 (<0.001***)		15.1 (<0.001***)	
Adjusted R-square	0.047		0.083		0.089	
P-value significance level: 10% (*), 5% (**), 1% (***)						

## DISCUSSION

In this cross-sectional analysis, we used baseline data collected as part of the MCLASS II cRCT. This study of 1746 households is the largest of its kind to measure PM<sub>2.5</sub> over a whole 24 hour period using low-cost air particle monitors in a LMIC setting, and the first to specifically investigate the use of such devices to assess SHS concentrations in homes in a LMIC setting. We show that it is feasible to conduct a large scale, population-based indoor air quality study in a LMIC. Just over half of our studied households allowed smoking in the home. These households tended to have fewer adult residents and bedrooms, access to outdoor space, and use natural gas/LPG for cooking in comparison to SFH. The difference in median daily household PM<sub>2.5</sub> concentrations was only 5 µg/m<sup>3</sup> (higher in SPH), much lower than estimates from HICs. For example, in the UK, one study found the difference to be 28 µg/m<sup>3</sup> between SPH (median 31 µg/m<sup>3</sup>, similar to than seen in our study of 32 µg/m<sup>3</sup>) and SFH (median 3 µg/m<sup>3</sup>).[25] Multiple factors can plausibly explain this difference. Outdoor PM<sub>2.5</sub> values are much higher in Dhaka than London or other cities in HICs. We purposefully took the indoor PM<sub>2.5</sub> measurements during the rainy season in Bangladesh to minimise the impact of outdoor

air pollution, as PM<sub>2.5</sub> concentrations are highly seasonal in Dhaka.[26] Furthermore, our study site, Mirpur, is in one of the most populated areas in Dhaka, and two large construction activities (metro rail and a flyover) were conducted in the last few years in this area, which might have elevated the background PM<sub>2.5</sub> level. However, our study is limited by a lack of data on outdoor PM<sub>2.5</sub> concentration over the course of the baseline measurement period. Continuous ambient air pollution data is available only from one monitor at the US Embassy in central Dhaka, far from Mirpur, which (given the local sources previously identified) is unlikely to represent local ambient PM<sub>2.5</sub>. Secondly, many of our study households were living in slums where housing is generally poorly constructed and likely to have high levels of outdoor to indoor air exchange. Another possible explanation of the high PM<sub>2.5</sub> concentrations measured in homes could be the use of insecticide mosquito coils that were burned inside some homes due to a dengue fever outbreak in Dhaka during our study period. Previous work has suggested that burning mosquito coils can generate PM<sub>2.5</sub> mass that is equivalent to several cigarettes.[27] Other plausible reasons for a smaller difference in PM<sub>2.5</sub> concentrations between SPH and SFH could be related to the behaviour of household members. For instance, a possible Hawthorne effect[28] may exist, which may influence participants' awareness and behaviour during the 24 hour PM<sub>2.5</sub> concentration measurement as devices were visibly present. Measuring for a longer period could be a possible solution to avoid this Hawthorne effect, however, a study in the UK[29] showed that the average of a full six days measurement provided similar results to the first 24 hours. Moreover, in SPH it is possible that smokers prefer to smoke outside the home when they are with friends, colleagues or common peer groups and, consequently, smokers in Dhaka city may smoke less frequently inside the home compared to smokers who smoke at home in the UK. This may also support our finding that



having outdoor space can reduce the PM<sub>2.5</sub> concentrations. Importantly, presence of a private outdoor space is a crucial factor for designing an intervention to reduce indoor SHS as this is an ‘opportunity’ in the COM-B model[30] (a behavioural system that connects three essential conditions: capability, opportunity, and motivation). According to this model, presence of this ‘opportunity’ can potentially influence the ‘motivational’ behaviour for keeping the home smoke free.

We found that use of kerosene as a cooking fuel was a strong predictors of indoor PM<sub>2.5</sub> concentrations. Other studies in LMICs have also found a similar association. For instance, in India, the PM<sub>2.5</sub> value was doubled among kerosene users compared to LPG users (mean 109, SD 14 µg/m<sup>3</sup> vs 57, 7 µg/m<sup>3</sup>), and in Nepal the PM<sub>2.5</sub> value was increased about 146% (95% CI 103 to 200%) in kerosene users compared to households that used electricity as a cooking fuel.[31, 32]

Our study also found that the daily household PM<sub>2.5</sub> concentrations decreased with an increase of each education year of the household lead participant. This is consistent with the literature that the education level of the household head is an important factor for keeping the household SHS-free. For instance, a study in Greece[33] showed that SHS exposure significantly declined with increase of education level. Furthermore, one study among women in Bangladesh showed the same association between SHS exposure and education level[34] as our study; however, another study in China[35] did not show any association.

Our regression results show a low adjusted R-square value (0.039-0.081 and 0.047-0.089), which explains that there are many possible explanatory variables that should be considered, given that different behavioural effects and lack of outdoor air pollution data are involved, as discussed earlier.

A likely potential driver for reductions in smoking prevalence in HICs is the implementation of smoke-free legislation in restaurants, bars and other public, indoor premises.[9] However, in many LMICs such legislation is often poorly implemented or enforced[36] and the social norms in the majority of homes in LMICs therefore still permit smoking indoors. Importantly, many smokers are unable to smell tobacco smoke, which makes them unaware of the level of tobacco-related exposure.[37] Considering these, an objective measurement is required to measure the concentration of SHS and to promote a smoke-free environment.[19, 38] In this study we measured the concentration of indoor SHS (PM<sub>2.5</sub>) and found that PM<sub>2.5</sub> is generally higher in smoking-permitted homes (SPH) compared to smoke-free households (SFH). Although this study showed the feasibility of implementing a large-scale indoor air quality study in LMIC settings, the small difference of PM<sub>2.5</sub> between SPH and SFP indicates to use PM<sub>2.5</sub> as a marker of SHS in such settings is challenging and would require confirmation through further studies in similar context. There are considerable practical challenges using optical particle counters such as the Dylos to measure exposure to SHS in LMIC settings.[39] Temperature and humidity can influence the measurement of PM<sub>2.5</sub> using these devices, though the effect is likely to have been systematic across both types of households given that we measured during the months when humidity is relatively stable across a 24-hour average.[40] Background or ambient PM<sub>2.5</sub> concentrations can also make it difficult to detect the additional

PM<sub>2.5</sub> generated by smoking indoors, particularly when smoking is only occasional. To address this we carried out our measurements during months when reference monitors from the US embassy indicated that ambient PM<sub>2.5</sub> concentrations were lowest and most stable. Our use of 1-minute time resolved data also facilitated identification of the differences between SFH and SPH as demonstrated in our figure 1.

This study was conducted only in urban setting and due to movement restriction in highly secured areas, the higher-income population could not be included. However, this was a large scale study with a big sample population, therefore, most of the urban features were captured. These findings can be shared with different stakeholders and policy makers in Bangladesh and other LMICs where there are high concentrations of SHS indoors. These data may help develop preventive interventions to encourage household members to reduce smoking indoors. Additionally, more research is required to understand what type of interventions have the potential to be effective in changing the behaviour of those smokers who continue to smoke indoors at home in LMIC settings.

## **Contributors**

TF prepared the manuscript, developed the analytical strategy, contributed to the statistical analysis, interpretation of the results, and wrote the first draft of the report. KS and RH conceptualised the study. SS led the design of obtaining PM<sub>2.5</sub> measurements. CF, RD, and SA contributed to statistical analysis and interpretation of the results. NDM and AM contributed to the interpretation of results and revision of the report. All authors participated in manuscript revisions, and read and approved the final manuscript.

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## **Competing Interests:**

All authors declared there is no conflict of interest.

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## **What this paper adds**

- Indoor PM<sub>2.5</sub> concentration is a well-established marker of second-hand smoke (SHS) exposure and has been widely used as an important indicator for evaluating indoor smoke-free policies in high-income countries (HICs).
- Little is known of the association between PM<sub>2.5</sub> and SHS in low-and-middle income countries (LMICs), where other variables such as high levels of ambient air pollution may cause distortion at a scale different from HICs.
- We found that in a typical LMIC urban setting PM<sub>2.5</sub> concentration can still differentiate between homes that permit smoking from those that don’t but the difference is significantly smaller compared to that observed in HICs.

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**Figure 1.** Distribution of PM<sub>2.5</sub> concentration at each minute by smoking policy in the home.

Note the logarithmic scale on the x-axis.